

Wireless Seismometer for Venus

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Abstract — Measuring the seismic activity of Venus is critical to understanding its composition and interior dynamics. Because Venus has an average surface temperature of 462 °C and the challenge of providing cooling to multiple seismometers, a high temperature, wireless sensor using a wide bandgap semiconductor is an attractive option. This paper presents progress towards a seismometer sensor with wireless capabilities for Venus applications. A variation in inductance of a coil caused by a 1 cm movement of a ferrite probe held in the coil and attached to a balanced leaf-spring seismometer causes a variation of 80 MHz in the transmitted signal from the oscillator/sensor system at 420 °C, which correlates to a 10 kHz/mm sensitivity when the ferrite probe is located at the optimum location in the coil.

Index Terms — Wireless Sensor, Seismometer, oscillator, high temperature circuits.

I. INTRODUCTION

Venus's internal structure and dynamics have not been studied, and the existing models of Venus's interior structure are based on extrapolations of Earth with correction factors to force the models to fit measurements and knowledge of the atmosphere [1], [2]. Thus, there is a critical need for seismic measurements on Venus. While some of these measurements may be made over a short time frame, understanding volcanic and seismic activity requires long term measurements. The most recent mission plan for Venus states that the seismometer must operate at least 117 Earth days, with 365 Earth days preferred [3]. Important science objectives can be accomplished with just 1 or 2 stations, although deploying additional stations would enhance the science return.

Venus has a very hostile environment with an average surface temperature of 462° C, an atmospheric pressure of 90 atm on the surface, and an atmosphere comprised primarily of CO₂ [3]-[6]. Thus, a seismometer must use an active cooling system if Si-based electronics are used or wide bandgap electronics, such as SiC and GaN, operating at the ambient temperature. Because the power requirements and weight of an active cooling system increase the mission costs and the need for a seismometer to be directly exposed to the environment, SiC electronics may be the better alternative if it can be shown to operate reliably for at least one year in the Venus environment. Wireless communication may be an asset because it would allow the seismometer to be deployed at

some distance from the parent spacecraft, partially decoupling the seismometer from oscillations created on the main spacecraft (Fig. 1). The circuit design also allows a straight-forward approach to convert the raw sensor signals into a form that can be transmitted and processed elsewhere.



Figure 1: Artist drawing of seismometer system operating on Venus. In an actual scenario on Venus, the seismometers are approximately 100 km apart.

An initial demonstration of a wireless seismometer for Venus was demonstrated in [8], but it had a sensitivity of 0.06 kHz/mm. In this paper, a high temperature, wireless seismometer sensor is described and measurements to verify the proof of concept are presented with a more than 100 times improvement in sensitivity.

II. SEISMOMETER

A seismometer that functions over the range of 0.3 mHz to 30 Hz, can potentially measure displacements of 10 nm and is operational to 462° C and pressures up to 90 bars is an objective for Venus measurements. INPROX Technology has developed a high temperature variable spring tension leaf-spring seismometer [7] utilizing a vertical pendulum design. A seismic mass consisting of ferrite material is counterbalanced with a leaf spring by means of a boom that is supported by crossed hinges in the conventional way. A thermal expansion compensation method is employed to compensate for the change in Young's modulus experienced by the spring as temperature changes. The ferrite seismic mass moves through a coil, creating a variable inductor that is employed as the transducer in the oscillator circuit. The inductance changes from 1.65 mH to 2.05 mH as the probe moves through the entire coil measured at 400 °C with an Agilent Impedance Analyzer.

III. OSCILLATOR DESIGN WITH INTEGRATED SEISMOMETER

The oscillator is based on a Clapp-type design, and its schematic is shown in Fig. 2. Because the self-resonant frequency of the seismometer's coil is approximately 500 kHz, the oscillator was designed to operate at 285 kHz without accounting for the bias circuits and the antenna. Note that the oscillator operates at an RF frequency that could be used for wireless transmission, and this frequency is not the frequency of the seismic activity that is being measured. The oscillator uses a Cree CRF24010 SiC MESFET, and the capacitors C_1 , C_2 , and C_T are ceramic chip capacitors. These components are attached to an alumina substrate with electrically conductive epoxy, and Au wire bonds are used for connections. A 70 cm diameter, multi-turn coil resonated with a capacitor, C_A , is used as the transmitting antenna. The coil antenna is fed with a single turn pick-up coil of the same diameter. The sensor inductor, L_T , of the seismometer is part of the oscillator resonant circuit. The bias supplies were noisy and degraded the oscillator characteristics. Thus, filters are used in the drain bias circuit, as shown in Figure 2, and a $10000\ \Omega$ resistor is used in the gate bias circuit. The element values are $C_{D1}=C_{D2}=2.5\ \mu\text{F}$, $L_{D1}=1.5\ \text{mH}$, $L_{D2}=2.68\ \text{mH}$, $C_1=1000\ \text{pF}$, $C_2=2000\ \text{pF}$, and $C_T=270\ \text{pF}$.

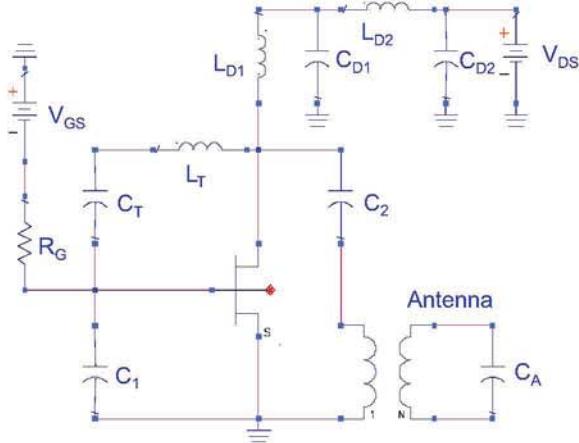


Figure 2: Schematic of seismometer.

IV. SEISMOMETER MEASUREMENT SETUP

High temperature testing of the wireless seismometer was performed in an oven. Because the coil antenna cannot radiate from within the oven, it is placed outside the oven; it and the bias circuits are the only parts of the system that are not at the temperature of the test. The receive antenna is a 50 kHz to 30 MHz ferrite loop antenna from Pixel Tech.; the receive antenna has a 27 dB low noise amplifier and a 22 dB gain amplifier was added.

The receive antenna is placed 10 m from the transmitting antenna in a typical laboratory environment. An Agilent spectrum analyzer is used to measure the received signal.

To minimize the effects of the oven fan and the vibrations from within the laboratory, a micromanipulator was used to adjust the boom position of the seismometer and hold the boom steady during the measurement. Thus, the seismometer is tested as a displacement sensor in this paper.

The oven temperature is controlled by an oven controller and maintains a temperature to within 1°C . To verify the oven temperature, a thermocouple is placed in the oven and positioned in the center of the oven. The thermocouple and the oven temperature controller agreed to within 2°C . A second thermocouple was placed on the brass plate to which the oscillator and seismometer were attached. Measurements were not made until the three thermocouples agreed to within 2°C . Thus, the carrier temperature of the oscillator and the air temperature were the same.

V. WIRELESS SEISMOMETER SENSOR MEASURED DATA

Figure 3 shows the measured spectra of the received signals as a function of probe position, with the seismometer at 420°C . The oscillation frequency is slightly higher than the designed frequency, but this is due to the incomplete model used for the transistor and circuit layout parasitic reactances. Also, it is seen that the magnitude is maximum at 310 kHz. This is due to the tuning of the antenna capacitance, C_A , and was done on purpose so that the oscillation frequency could be determined from the signal magnitude.

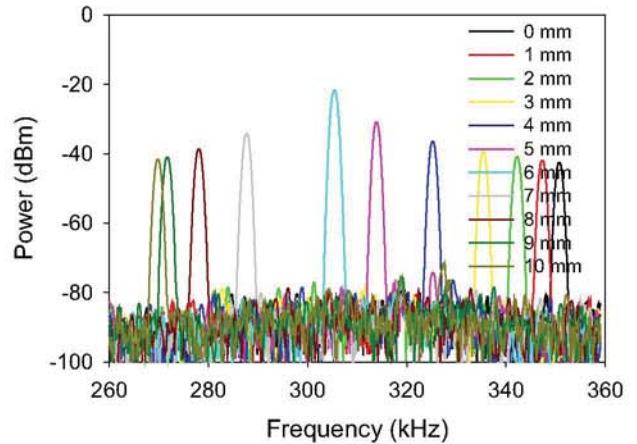


Figure 3: Measured spectrum at $420\ ^\circ\text{C}$.

The frequency of the signal as a function of probe position and temperature is shown in Fig. 4. The total variation of signal frequency is approximately 80 MHz. The maximum variation of the frequency occurs when the

probe is placed at 5 mm. In the 2 mm range centered at 5 mm, the ratio of the variation in frequency to probe displacement, or the seismometer sensitivity, is 10 kHz/mm. Figure 5 shows the measured power level as a function of the probe displacement. It is seen that the variation in received power over a 2 mm range of probe displacement is approximately 15 dBm, which indicates that a simple diode power detector may be used to measure the probe displacement.

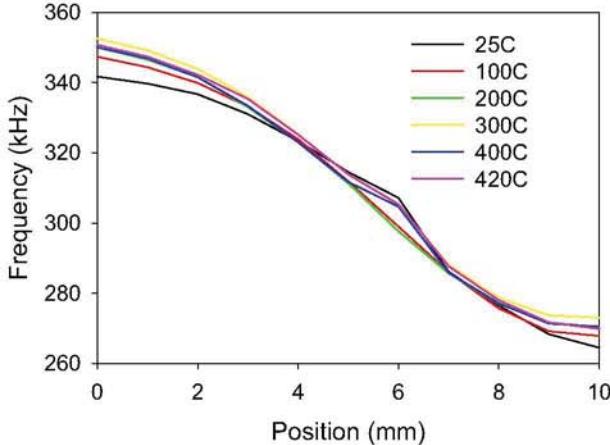


Figure 4: Measured oscillation frequency as a function of probe displacement and temperature.

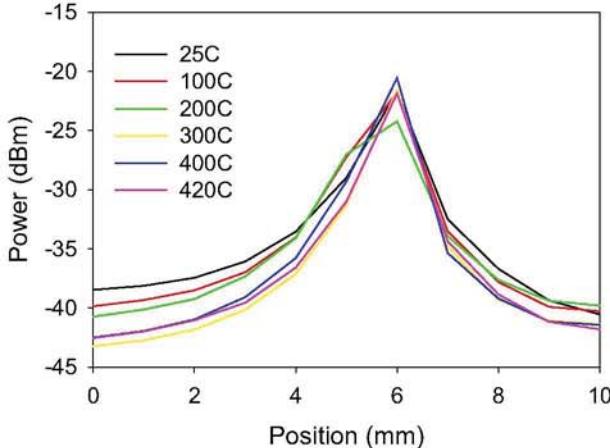


Figure 5: Measured received power as a function of the probe displacement and temperature.

VI. CONCLUSION

This paper has presented a proof-of-concept design of a high temperature, wireless seismometer sensor for Venus. The oscillator with the integrated seismometer sensor operated well through 420° C, but decreased signal to noise ratio did not allow operation through the required

temperature of 462 °C. Although the sensitivity of this seismometer is approximately 166 times greater than the one demonstrated in [8], it is still too low to meet all the needs for a Venus mission. With the sensitivity of 10 kHz/mm, a detection of 10 nm displacement would result in a frequency variation of only 0.1 Hz, which is too small for accurate detection with the spectrum analyzer and the noise of the oscillator at 420 °C. Further work must be done to improve this. The seismometer demonstrated here used a better antenna design than the one in [8], and it allowed true far field radiation. The 10 m distance between the receiver and transmitter was only limited by the size of the laboratory. Finally, the Cree transistors, which are not designed for high temperature operation, have been operated at 475 °C for 73 hours before they started to fail, which is not sufficient for a long-term Venus mission.

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